Distinguishing response behaviors within cumulative noise metrics for Quiet Supersonic Flights 2018 data

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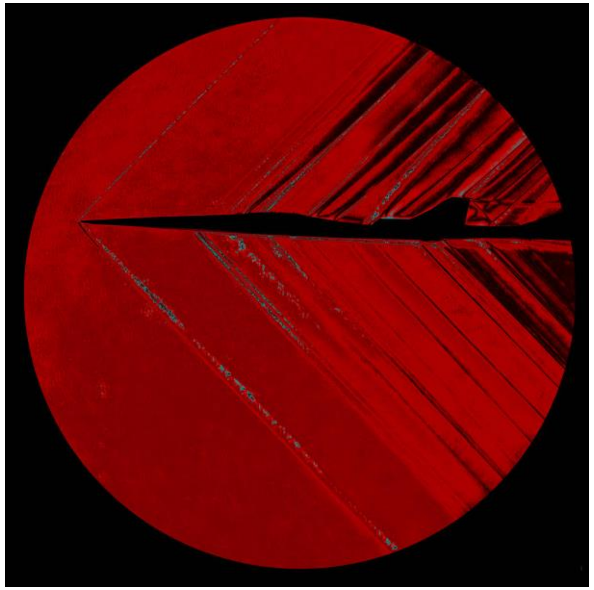
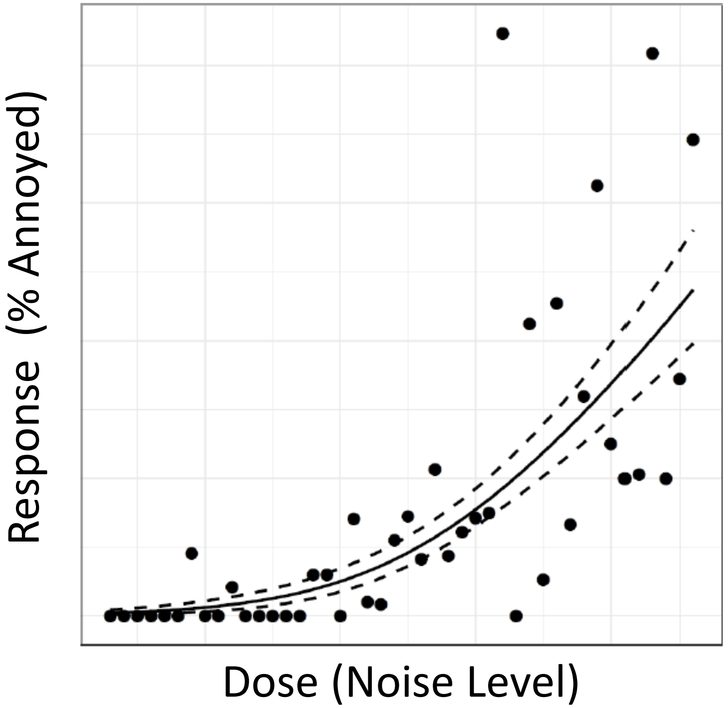
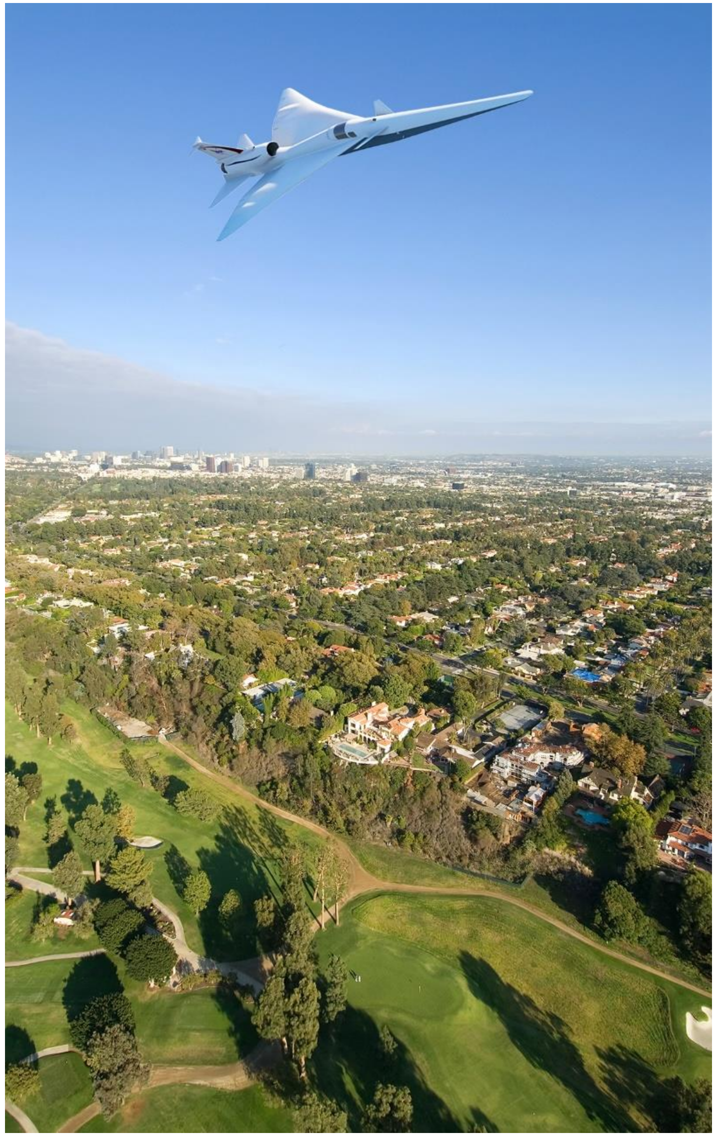
Introduction

- **Upcoming X-59 community tests**
  - Ban on overland commercial supersonic flight
  - Shaped-boom technology → Quiet supersonic flight
  - Noise dose and annoyance response data to inform regulators
- **How do people respond to multiple supersonic overflights in a day?**







Dose-Response Data

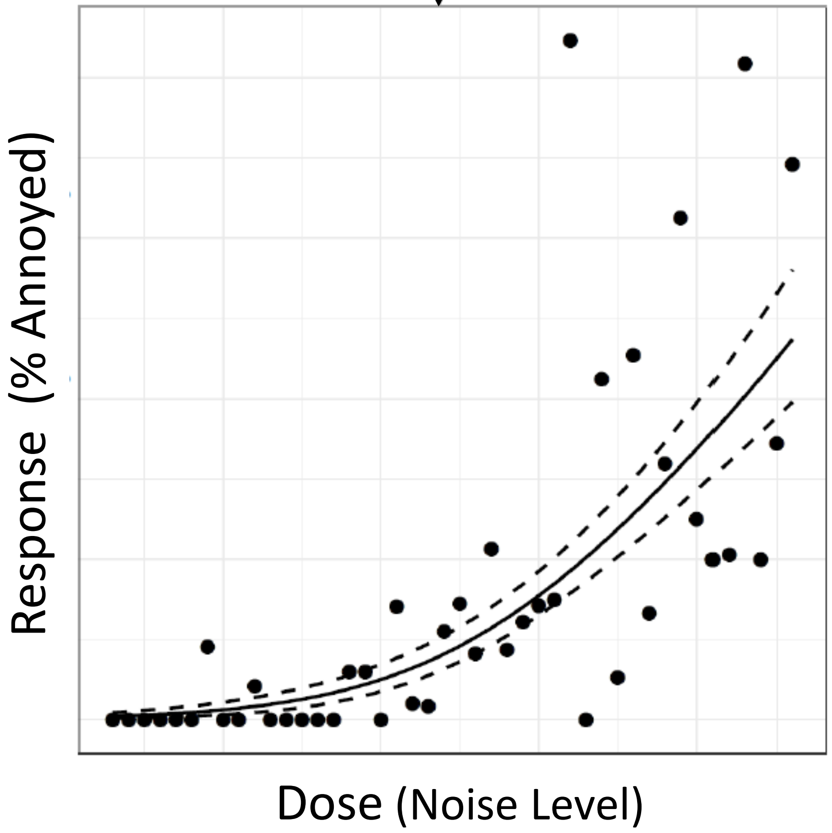
How much did the sonic boom bother, disturb, or annoy you?

1 2 3 4 5

Convert to binary "Highly Annoyed" (HA) response

Participant ID	Event Number	Dose (Noise Level)	Annoyance Response
001	1	70	0
001	2	81	1
001	3	74	0
002	1	72	0
002	2	78	0

Fit Statistical Model



Single-Event and Cumulative Dose-Response Data

- **Longitudinal (panel) Study Design:** each participant responds to multiple events
  - Single Event (SE)
    - Responses to individual flyovers
    - Perceived Level (PL) [dB]
  - Cumulative
    - Response from end-of-day survey
    - Perceived Day-Night Level (PLDNL) [dB]
      - Summation of single events (SE_i) in one day:

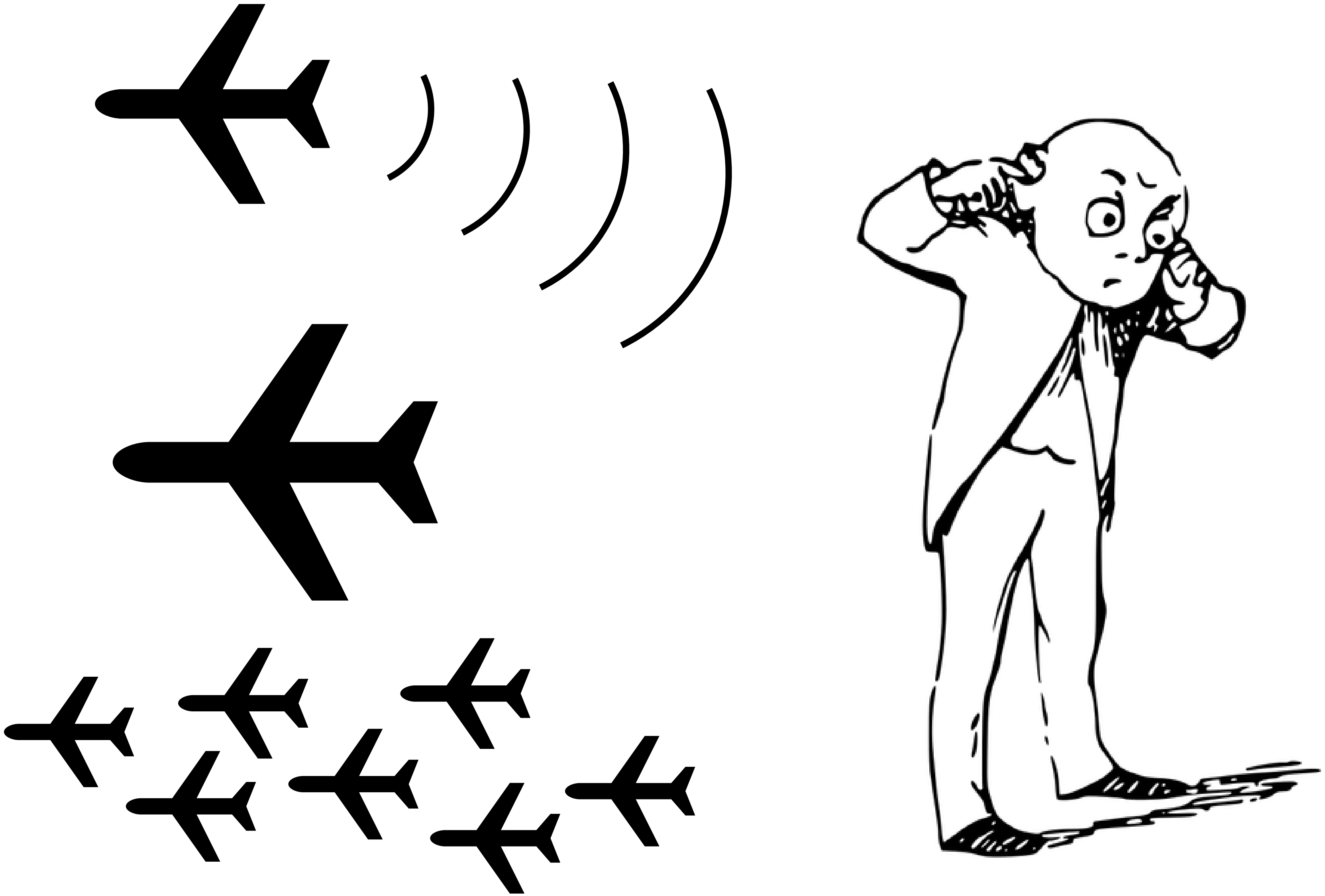
$$\boldsymbol{L_{dn} = 10\log_{10}\left(\sum_i 10^{\mathrm{SE}_i/10}\right) - 49.4}$$

Participant ID	Event Number	Dose (PL)	Annoyance Response
001	1	70	0
001	2	81	1
001	3	74	0
002	1	72	0
002	2	78	0

Participant ID	Day	Dose (PLDNL)	Annoyance Response
001	1	32.7	1
002	1	29.6	0

Potential Predictors of Cumulative Annoyance

- **Day-Night Level (DNL)**
  - Equal Energy Hypothesis
    - Level
    - Duration
    - Number of events
- **Loudest single event**
  - Peak-End Rule
- **Number of events**
  - Noise and Numbers
    - E.g., Fields 1983



Introducing ב ("Bet")

- Reformulating DNL equation:

$$L_{dn,ב} = 20\log_{10}\left[\left(\sum_{i=1}^{N}\left(10^{\frac{SE_i}{20}}\right)^{ב^{-1}}\right)^{ב}\right] - 49.4$$

- Based on generalized vector norms ($ב = p^{-1}$)
- ב ("bet") is bounded from 0 to 1
- Interpretation given in table:

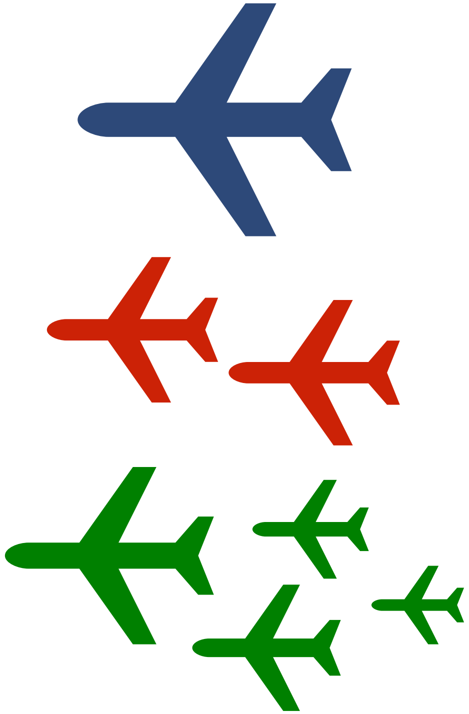
ב	p-norm	$L_{dn,ב}$ returns:	Importance given to:
0	∞	Maximum of SE_i vector	**Loudest Single Event**
0.5	**2**	Original DNL	**Equal Energy**
1	**1**	Coherent summation	**Number of Events**

ב Example

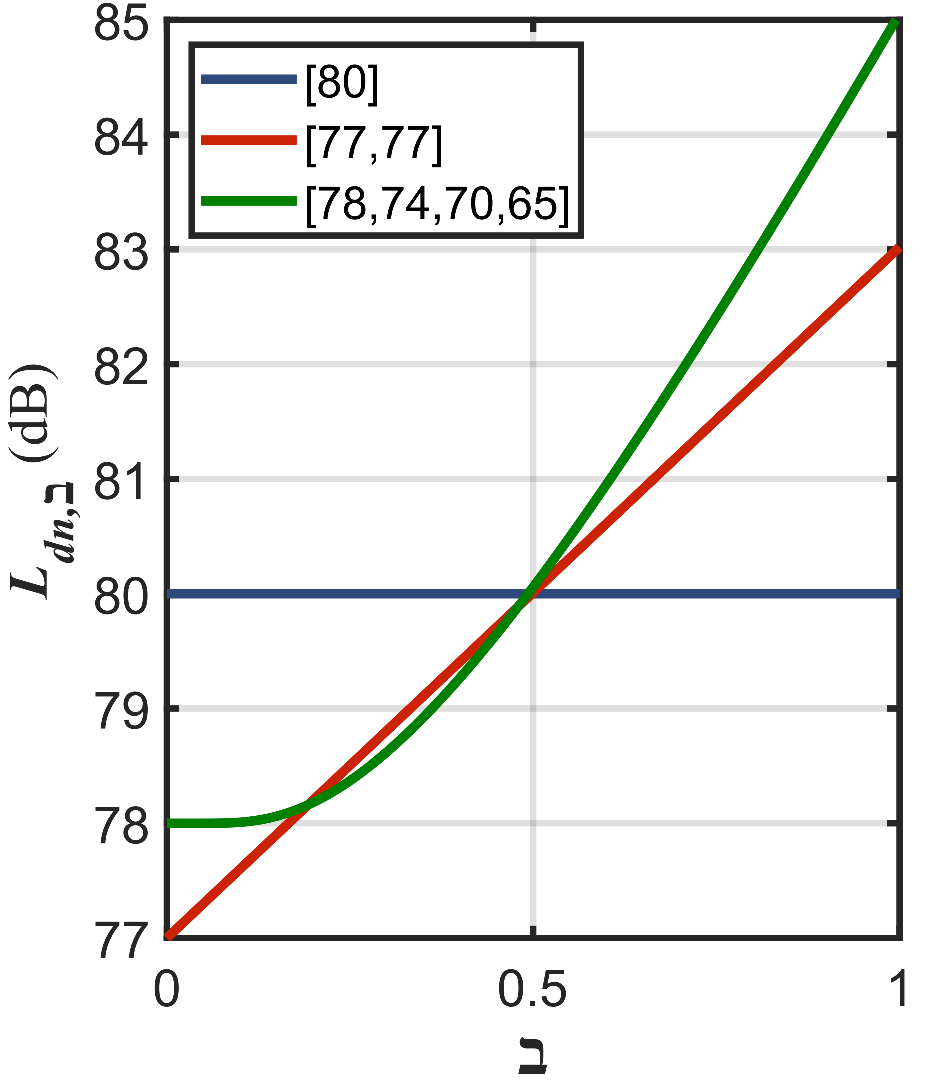
- Consider 3 combinations of SE:
  - $SE_i = [80]$ (dB)
  - $SE_i = [77, 77]$ (dB)
  - $SE_i = [78, 74, 70, 65]$ (dB)
- Combine using $L_{dn,\text{ב}}$:

$$L_{dn,\text{ב}} = 20\log_{10}\left[\left(\sum_{i=1}^{N}\left(10^{\frac{SE_i}{20}}\right)^{\text{ב}^{-1}}\right)^{\text{ב}}\right] - \cancel{49.4}$$

(For simplicity, drop 49.4)



ב	$L_{dn,\text{ב}}$ (dB)	$L_{dn,\text{ב}}$ (dB)	$L_{dn,\text{ב}}$ (dB)	Importance given to:
0	80	77	78	Loudest Single Event
0.5	80	80	80	Equal Energy
1	80	83	85	Number of Events



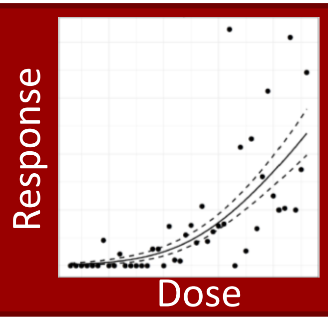
ב Analysis Methods

For each ב value from 0 to 1 in small (0.001) increments:

1) Calculate $L_{\text{dn},\text{ב}}$ values:

$$L_{dn,\text{ב}} = 20\log_{10}\left[\left(\sum_{i=1}^{N}\left(10^{\frac{SE_i}{20}}\right)^{\text{ב}^{-1}}\right)^{\text{ב}}\right] - 49.4$$

2) Fit logistic curve to $L_{\text{dn},\text{ב}}$ dose-response data:



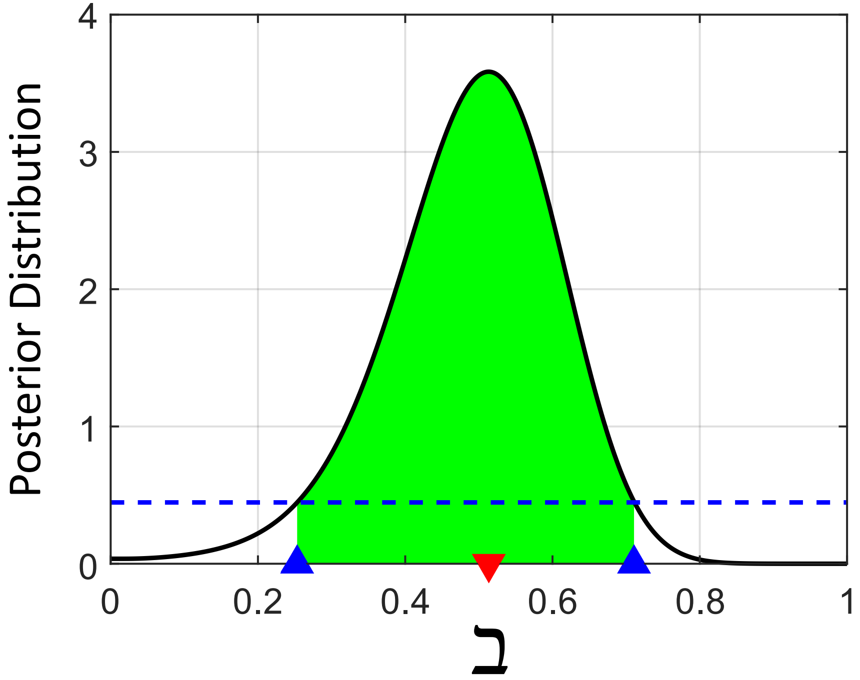
3) Evaluate Log Likelihood:
"the likelihood of the data given ב"

$$L_{dn,\text{ב}}(\text{Data}|\text{ב}) = \log\left(\prod_{i=1}^{n} A^{\text{HA}}(x_i)\left[1 - A^{\text{nHA}}(x_i)\right]\right)$$

4) Compute Posterior Distribution:
"the probability of ב given the data"

$$Po(\text{ב}|\text{Data}) = \frac{L_{dn,\text{ב}}(\text{Data}|\text{ב}) \cdot Pr(\text{ב})}{P(\text{Data})}$$

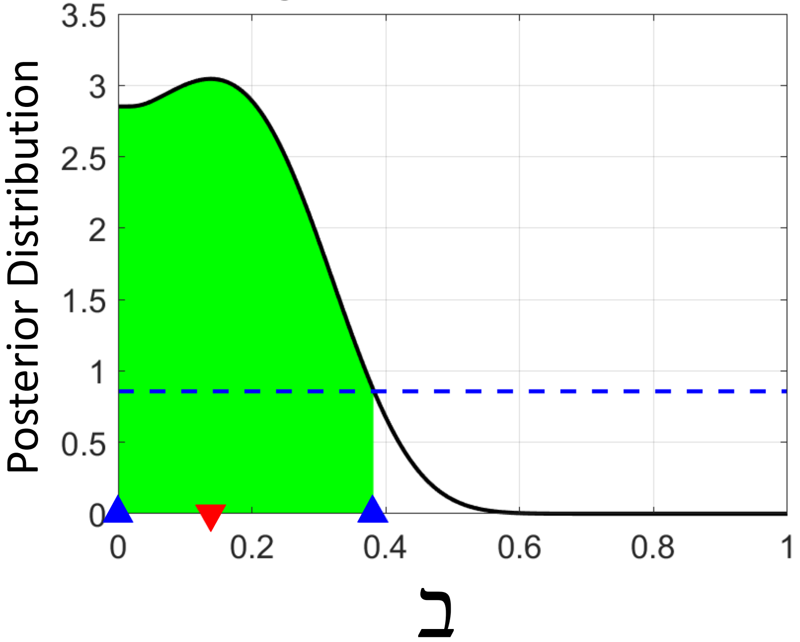
5) Plot ב Posterior Distribution:



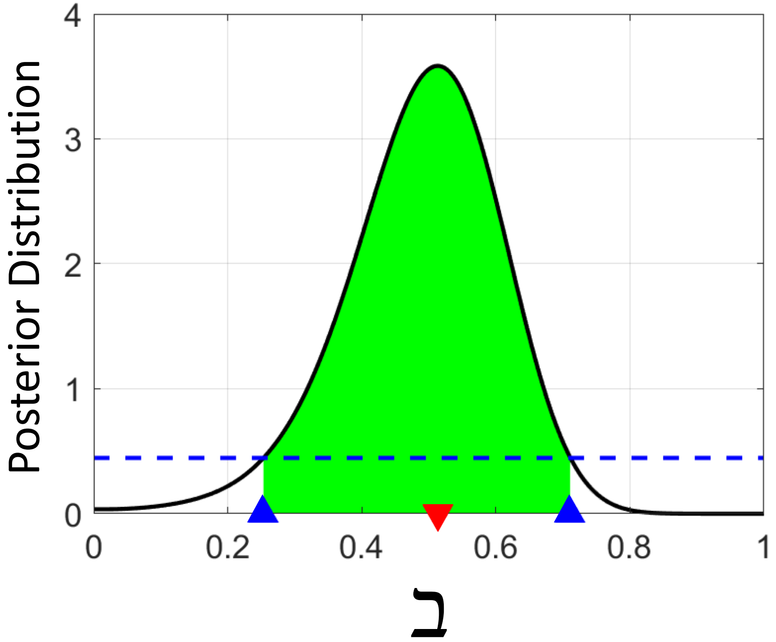
Examples of Potential ב Results

- Plots not from real data, only illustrative of potential results
- Questions to consider when interpreting results:
  - Where is the peak?
  - How narrow/broad is the peak?
  - What ב values can be rejected?

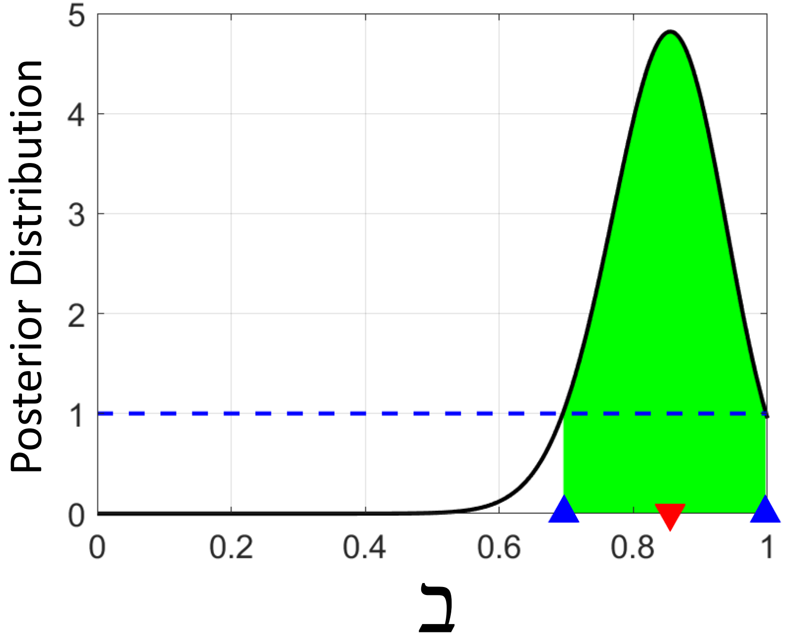
Loudest Single Event



Equal Energy

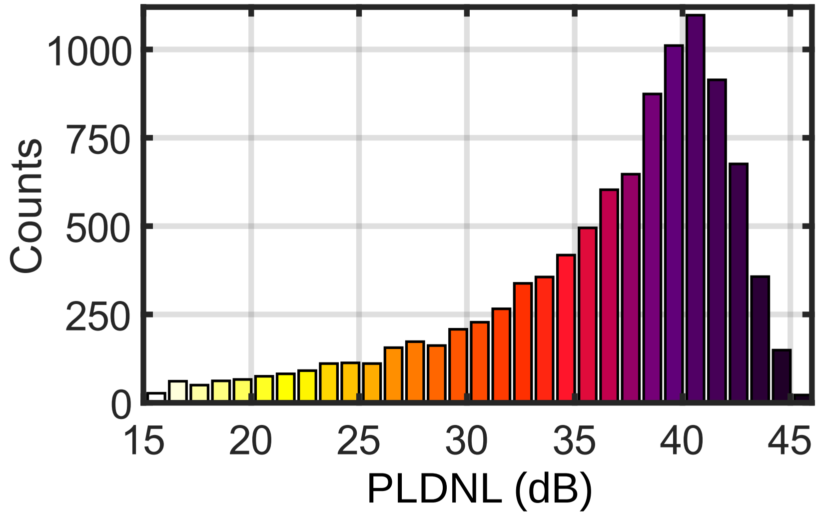


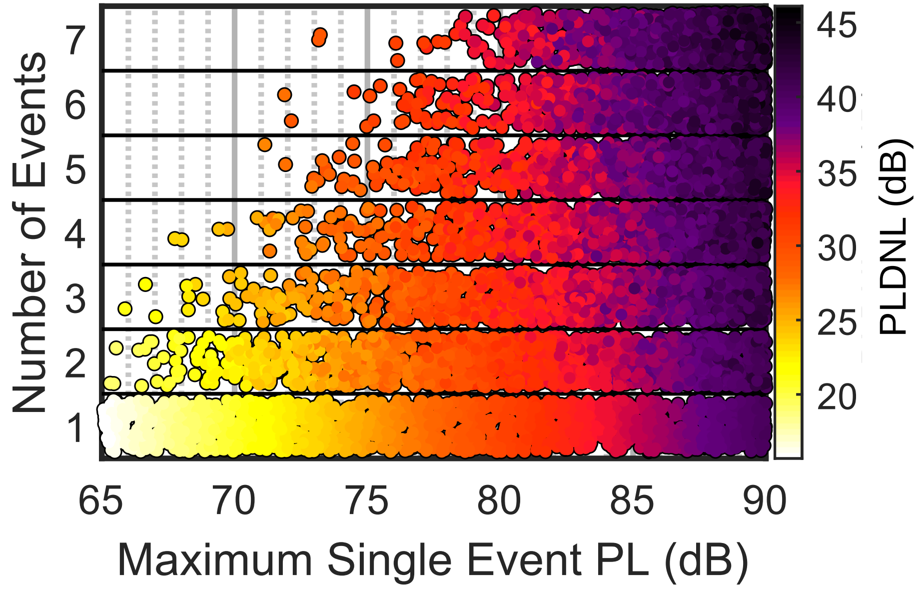
Number of Events



Simulation Dose Data

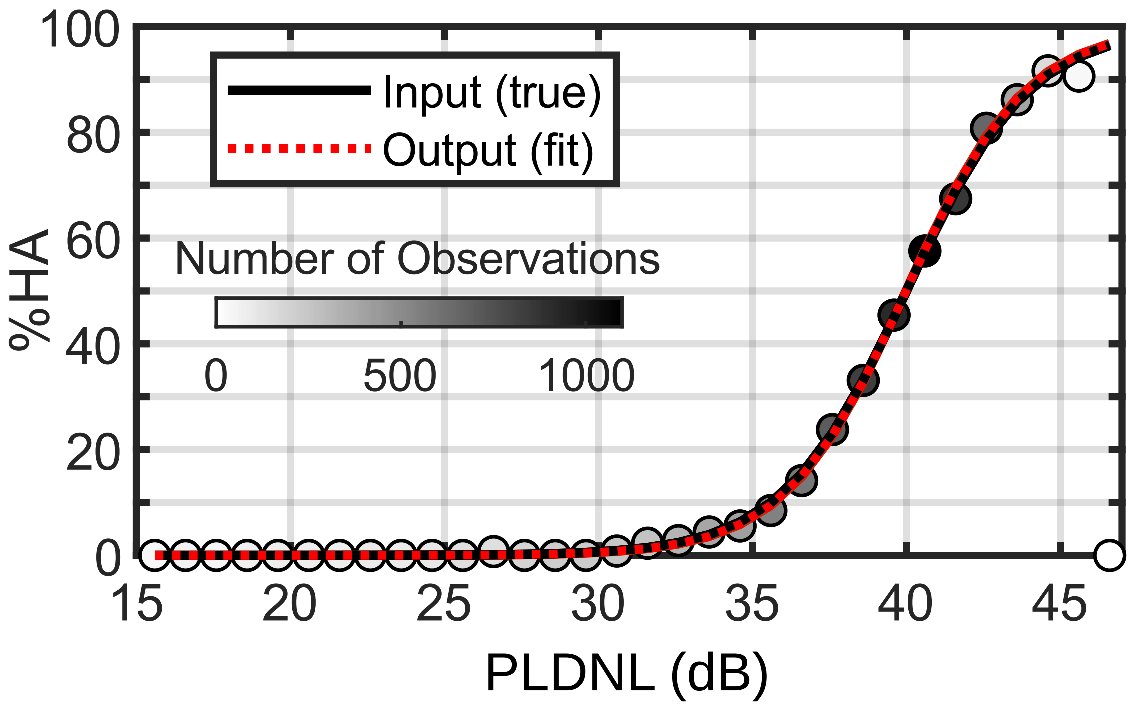
- **Simulation goals:**
  - **Demonstrate ב analysis**
  - **Provides context for understanding QSF18 results**
- 10,000 cumulative dose-response pairs
- Dose:
  - Number of single events: 1 to 7 from uniform distribution
  - Single-event dose range: 65 to 90 dB from uniform distribution
- Maximum Single Event PL vs Number of Events
  - Top left corner empty
    - Due to logarithmic relationship & uniform distributions
- Need to define responses

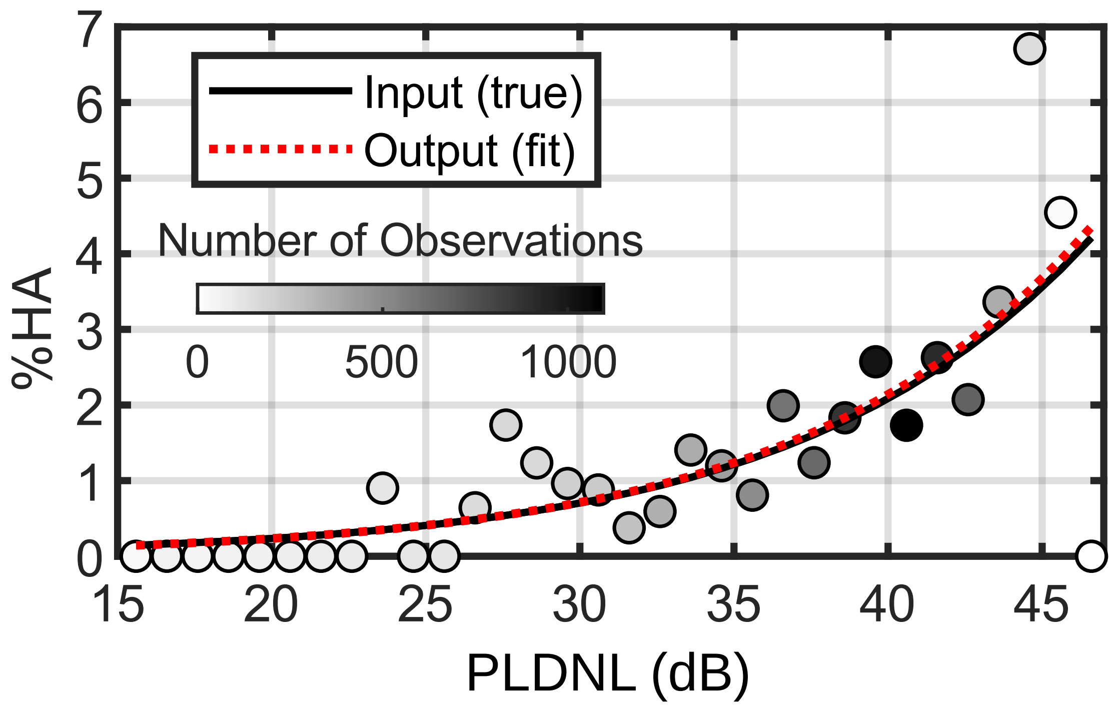




Simulation Response Data

- Simulations with same doses but differing responses
- Specify $\beth = 0.5$ as “true” response
  - **Simulation 1**:
    - Fully Sampled Dose-Response Curve
    - %HA from 0 to almost 100%HA
  - **Simulation 2:**
    - Poorly Sampled Dose-Response Curve
    - %HA from 0 to about 4%HA

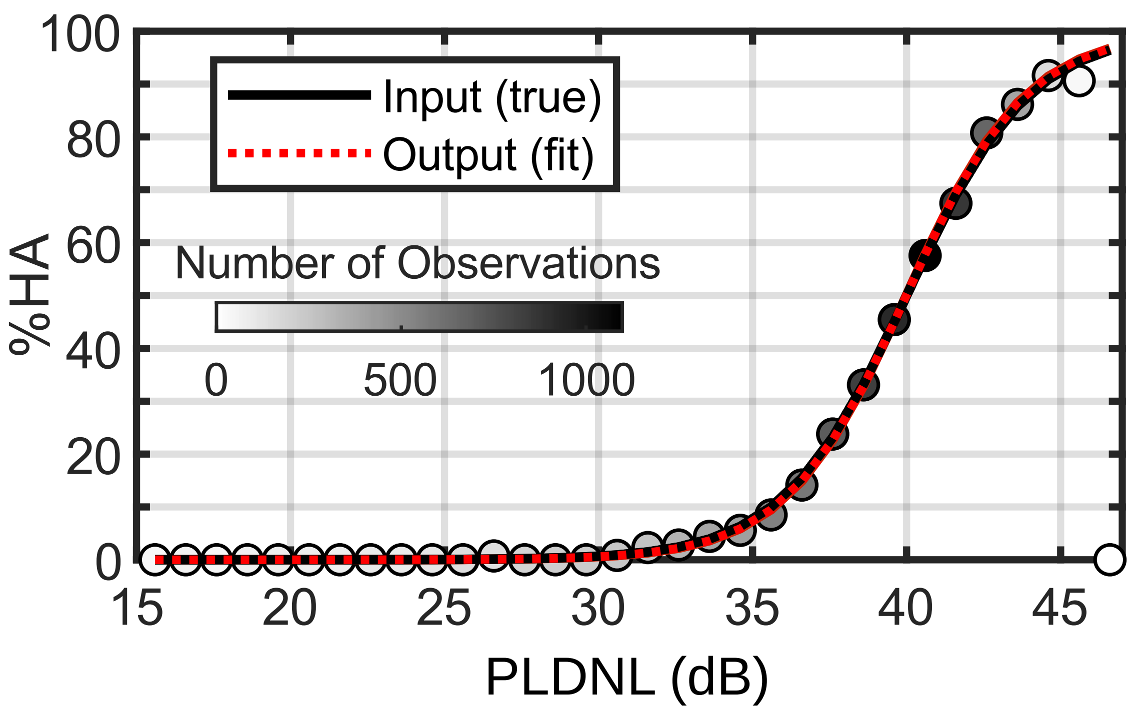


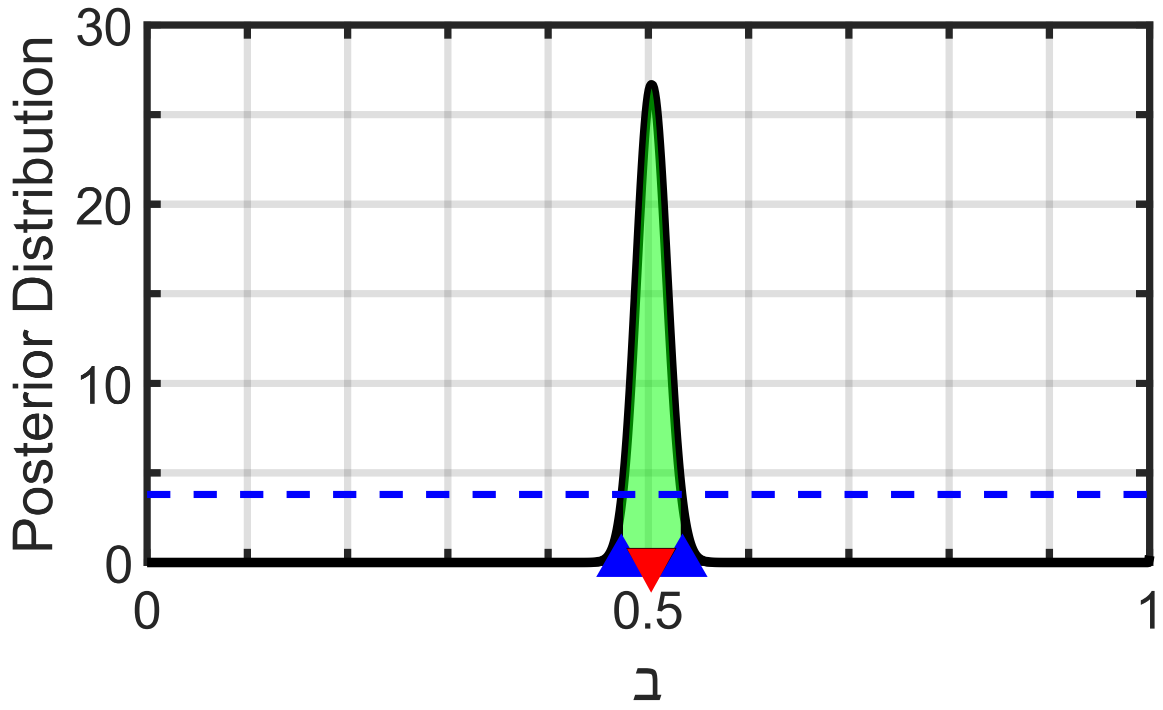


Simulation 1 Results: Fully Sampled Dose-Response Curve

- Where is the peak?
- How narrow/broad is the peak?
- What ב values can be rejected?

- ב $\cong 0.5$; **accurate**
- Narrow peak; **precise**
- ב $= 0$ & 1 **can be confidently rejected**

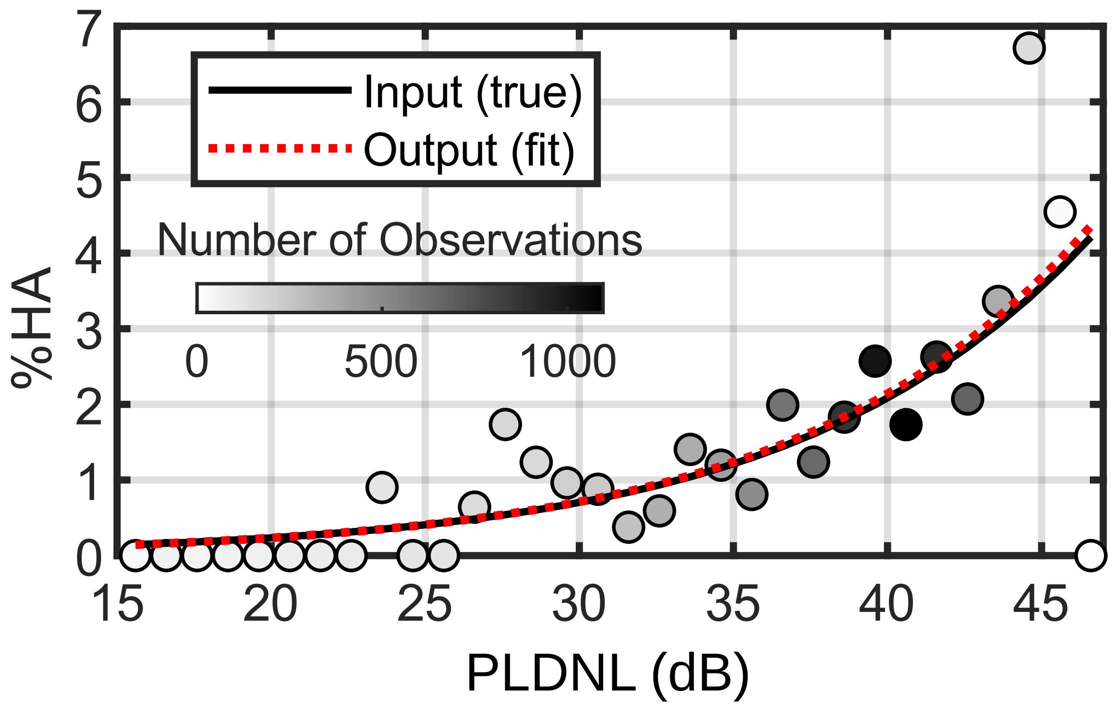


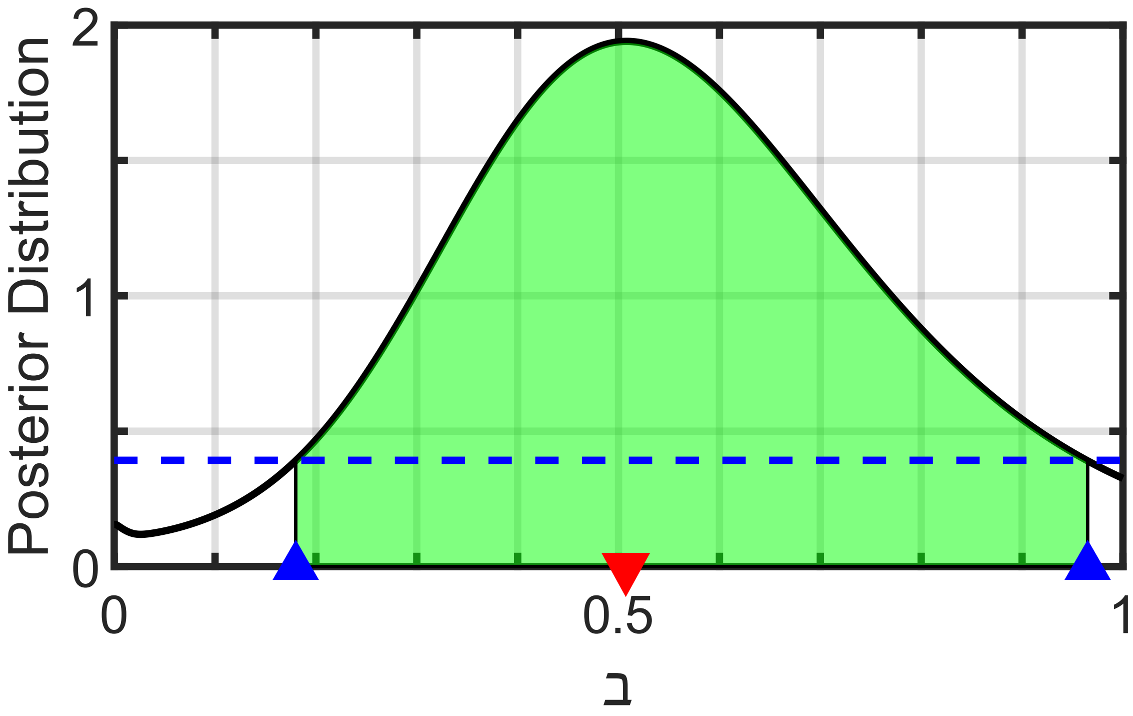


Simulation 2 Results: Poorly Sampled Dose-Response Curve

- Where is the peak?
- How narrow/broad is the peak?
- What ב values can be rejected?

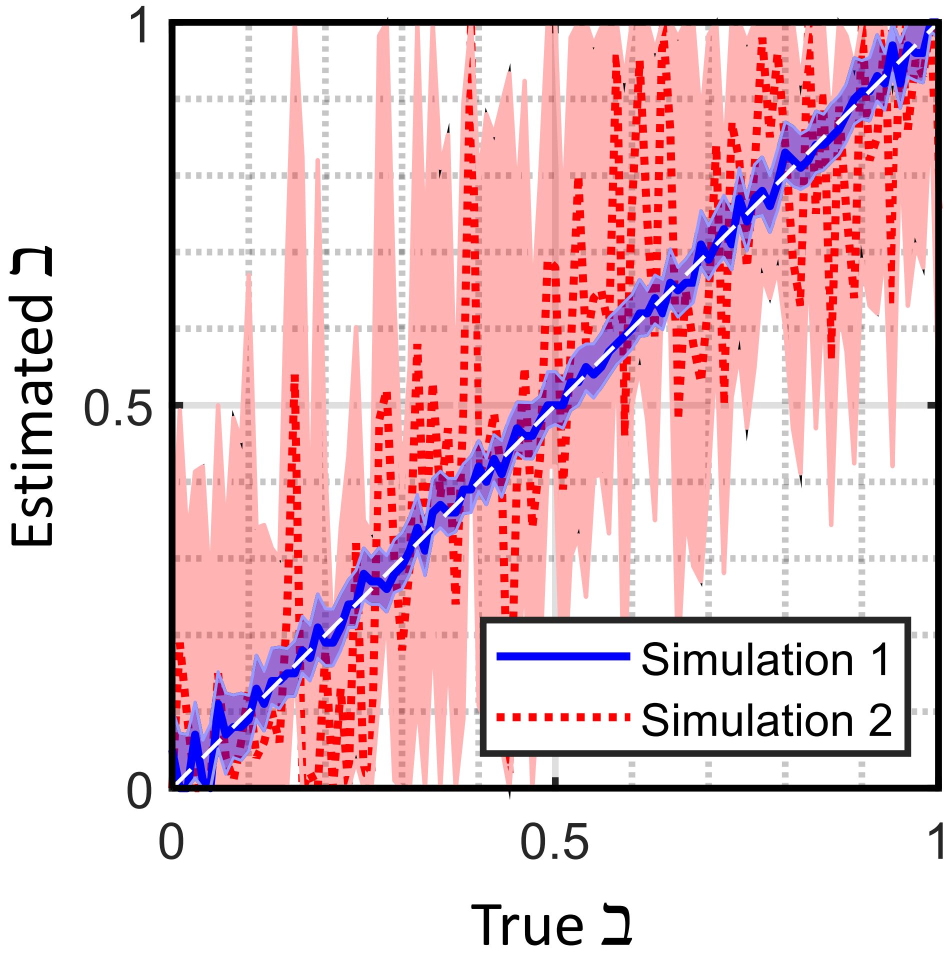
- ב $\cong 0.5$; **somewhat accurate**
- Very broad peak; **not precise**
- ב $= 0$ & 1 **<u>cannot</u> be confidently rejected**





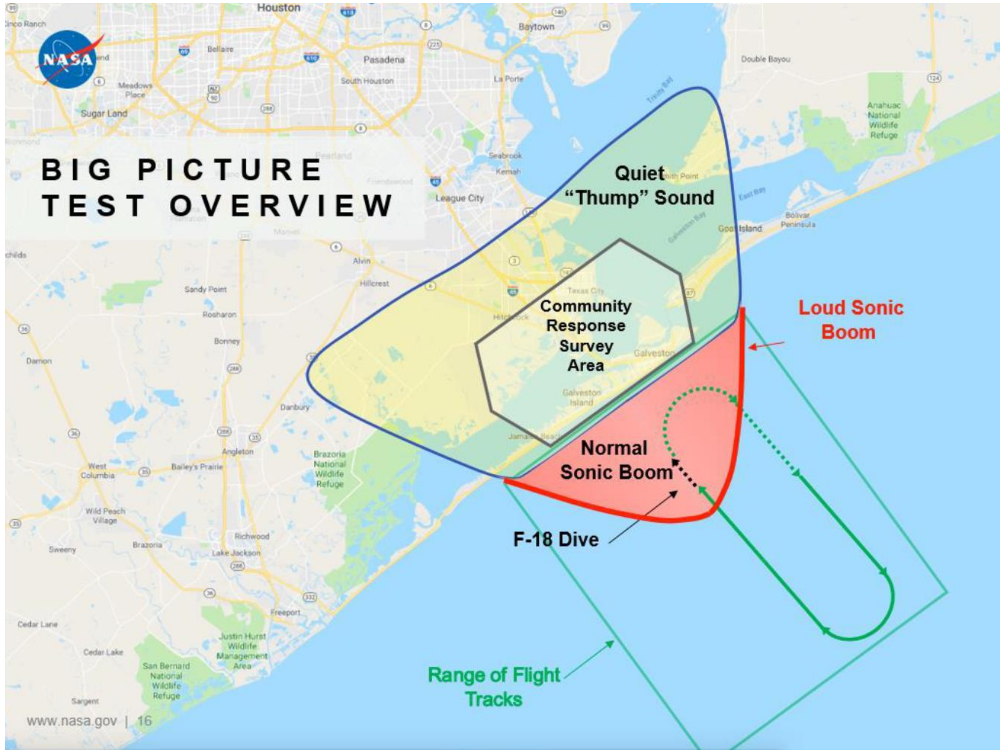
Simulation Results for Various Input ב Values

- Previous examples set input ב to 0.5
- Now vary ב from 0 to 1 in 0.01 steps for both cases
  - Simulation 1 is fully sampled dose-response curve
  - Simulation 2 is poorly sampled dose-response curve
- Results:
  - Both simulations are accurate
    - Input ב captured within output ב CI
  - Simulation 1 more precise
  - Simulation 2 rejects fewer ב values



Quiet Supersonic Flights 2018 (QSF18)

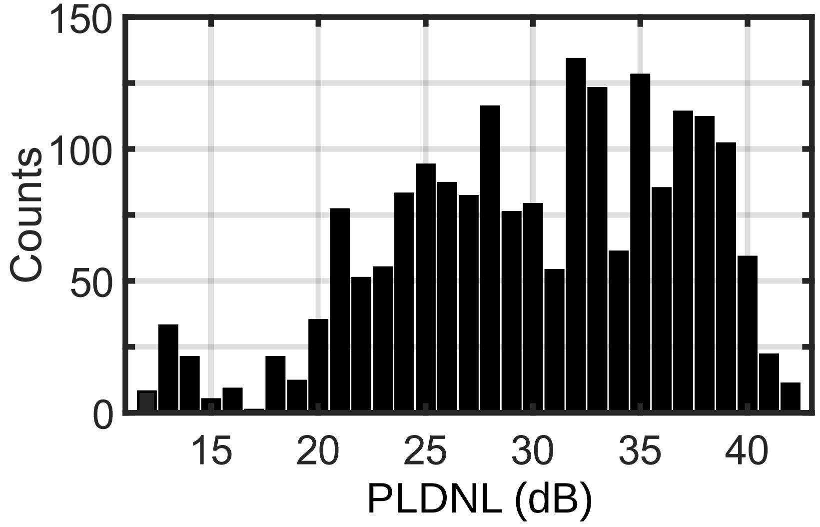
- Galveston, Texas in November 2018
- Low-amplitude sonic booms via F-18 dive maneuver
- 9 Flight days
  - 52 total flyover events
- 385 provided ≥ 1 cumulative response
- **1952 total cumulative dose-response pairs**



QSF18 Dose-Response Data Summary

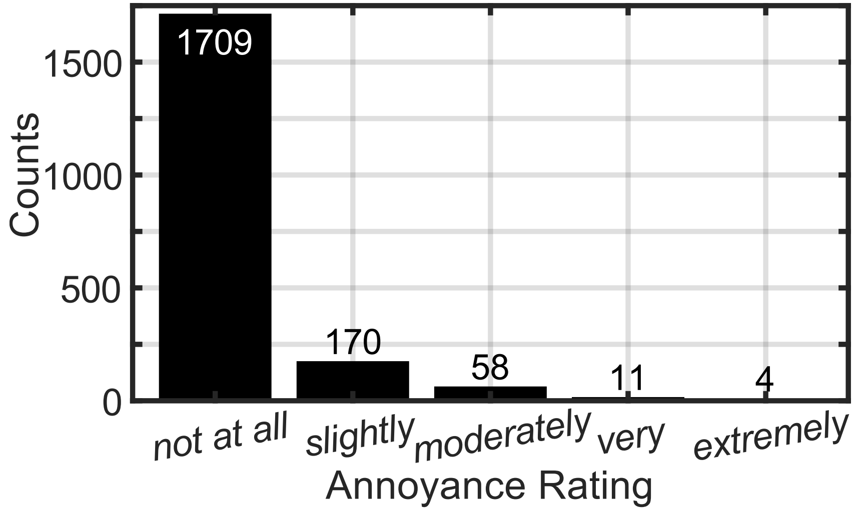
Cumulative Dose

- 1,952 cumulative doses calculated from 8,704 single events
- Cumulative range in PLDNL: 7.3 to 41.1 dB



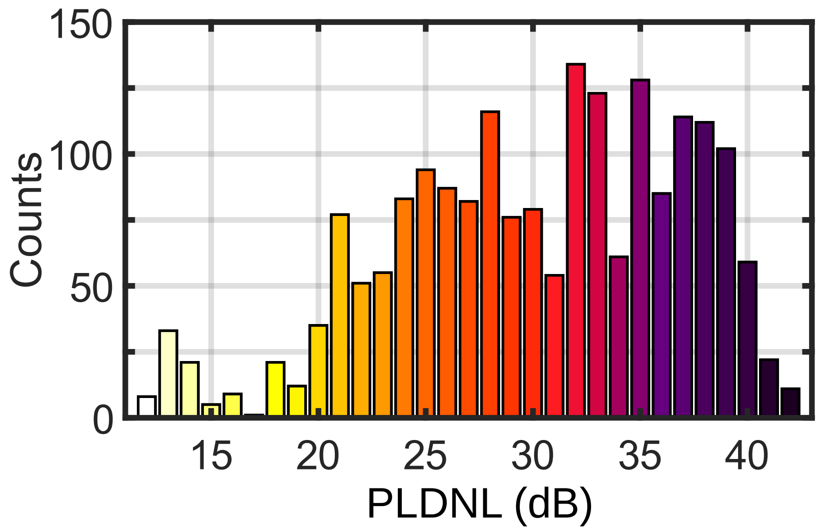
Cumulative Response

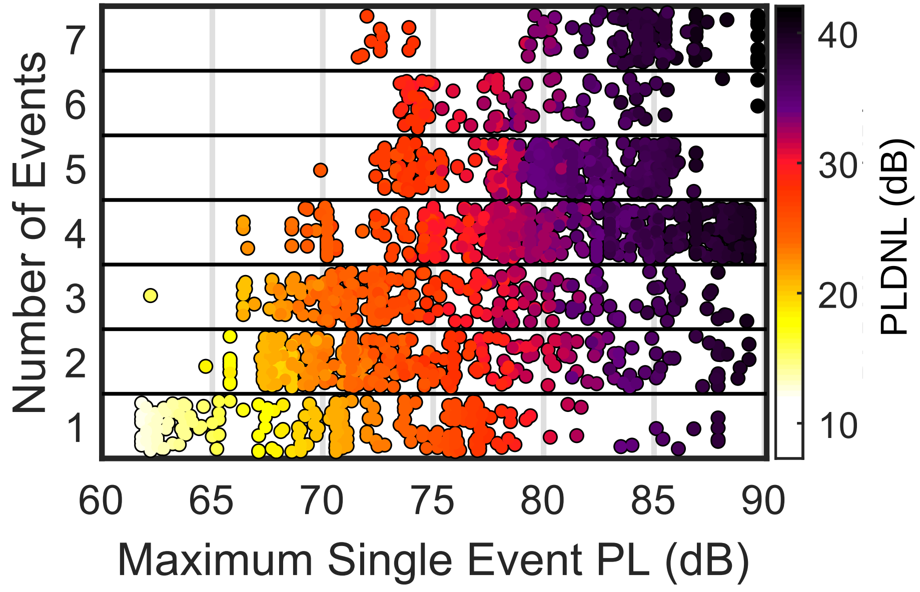
- 5-point verbal response scale
- Few annoyed responses
  - 15 (<1%) highly annoyed (HA)
  - 73 (4%) at least moderately annoyed (MA+)
  - 243 (12%) at least slightly annoyed (SA+)



QSF18 Data: Max Single Event Level vs Number of Events

- Maximum Single Event PL vs Number of Events plot with DNL noted in color describes tested ב space
- Maximum Single Event PL:
  - Ranges from 63 to 90 dB
- Number of Events:
  - 4 to 8 planned events per day (1 to 7 measured)
  - Doses only assigned when certain conditions met
- Multiple ways to achieve the same DNL
  - Trend dominated by maximum single event level due to logarithmic relationship

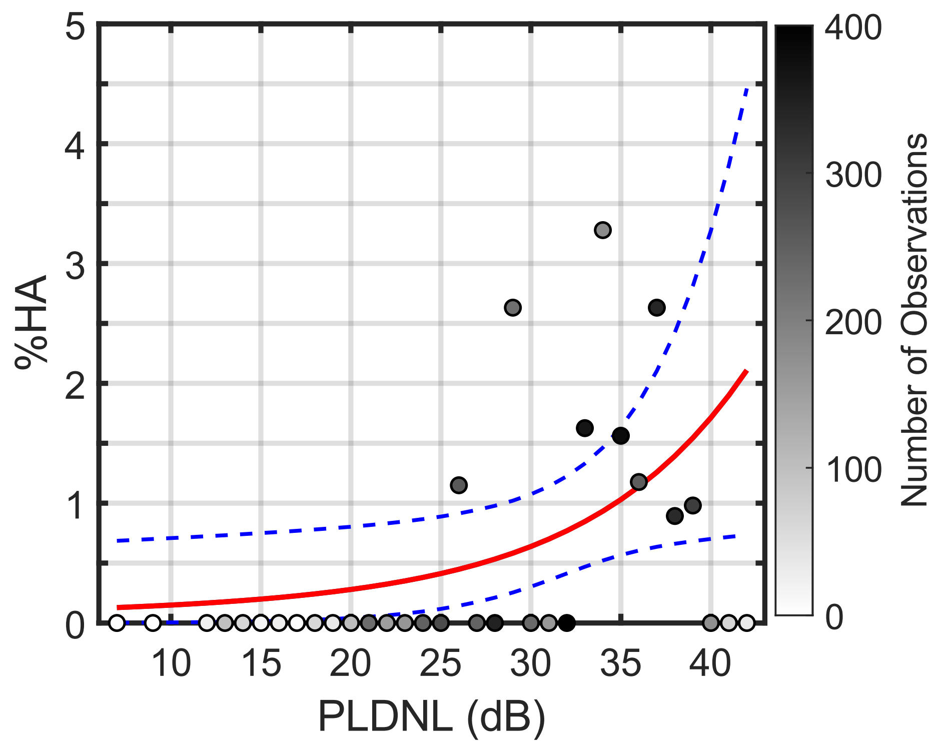


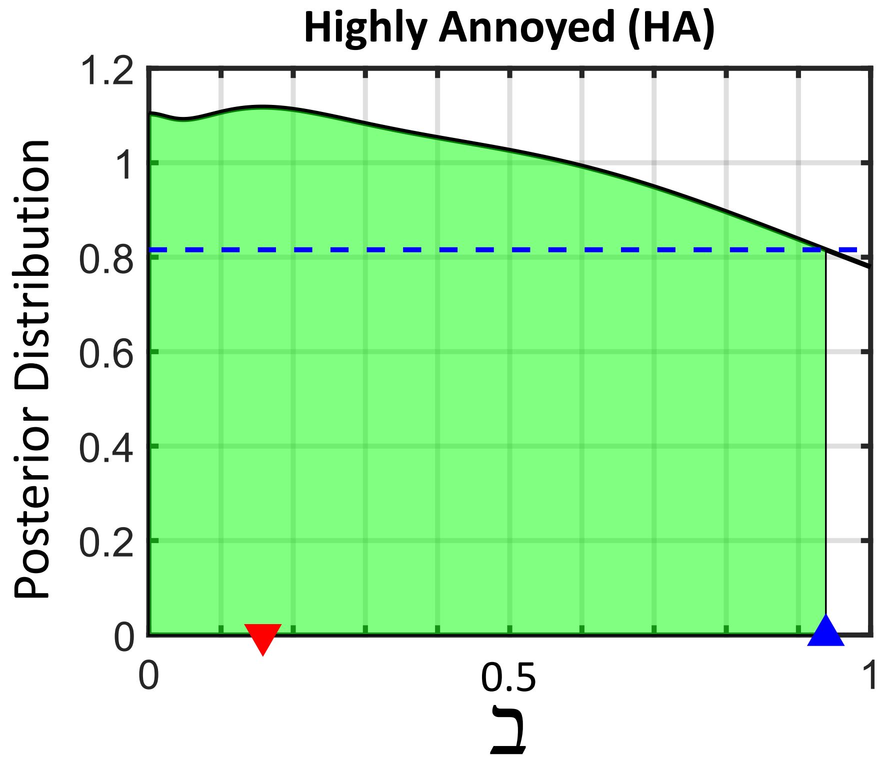


QSF18 ב Posterior Distribution Results for HA

- Where is the peak?
- How narrow/broad is the peak?
- What ב values can be rejected?

- ב ≈ 0.16 for HA
- Very broad peak; **not precise**
- **ב = 1 is weakly rejected**



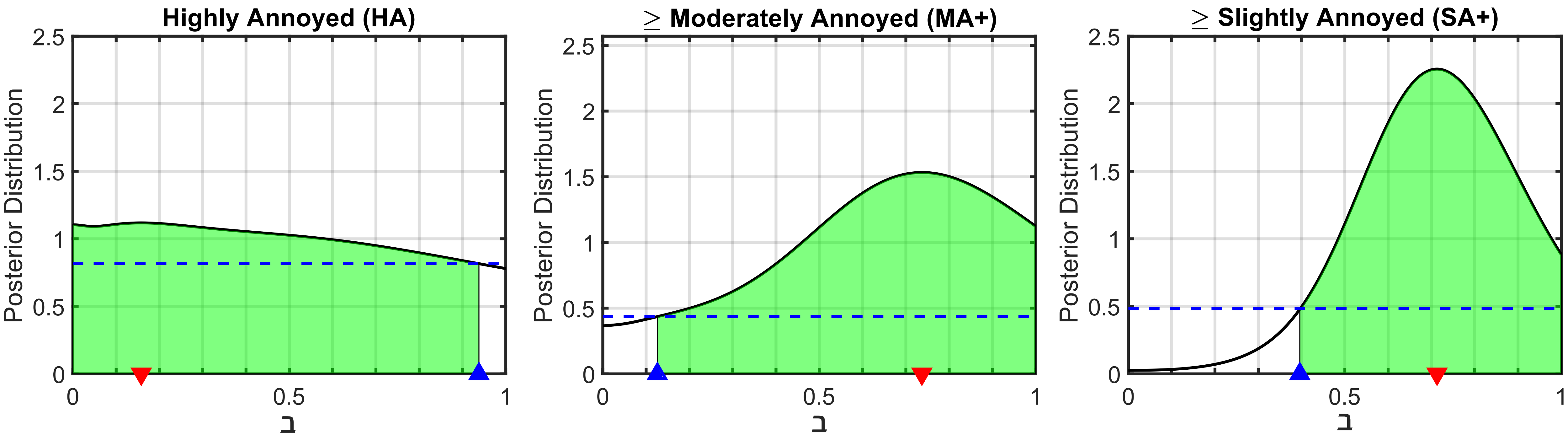


QSF18 ב Posterior Distribution Results for HA, MA+, & SA+

- Where is the peak?
- How narrow/broad is the peak?
- What ב values can be rejected?

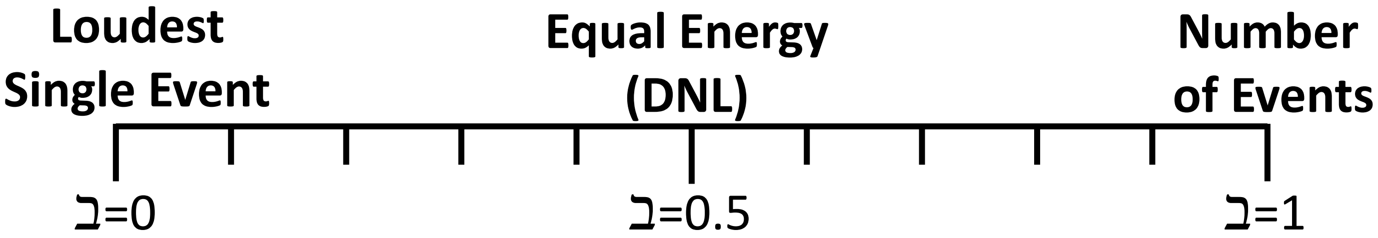
- ב ≈ 0.16 for HA; ב ≈ 0.72 for MA+ & SA+
- Very broad peak; **not precise**
- **ב = 0 is rejected by MA+ & HA+**

People who are differently annoyed may be annoyed differently



Conclusion

- ב ("bet") analysis works and provides insight into cumulative dose-response relationship



- Test design is important
  - Simulation demonstrates ב analysis
  - QSF18 results are limited
  - Framework for future analysis of X-59 community data
- ב analysis is applicable to other noise studies
- Manuscript on ב analysis in progress